Workshop on Aerodynamic Issues of Unmanned Air Vehicles

Emerging Aerodynamic Technologies for High-Altitude Long-Endurance ‘SensorCraft’ UAVs

Dr. Carl P. Tilmann

Air Force Research Laboratory

Air Vehicles Directorate

Aeronautical Sciences Division

Aerodynamic Configuration Branch

4 November 2002

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **26 JUL 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Emerging Aerodynamic Technologies for High- Altitude Long-Endurance SensorCraft UAVs**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory Air Vehicles Directorate Aeronautical Sciences Division Aerodynamic Configuration Branch**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001685, CSP 02-5078, Proceedings for Aerodynamic Issues of Unmanned Air Vehicles (UAV)., The original document contains color images.

14. ABSTRACT

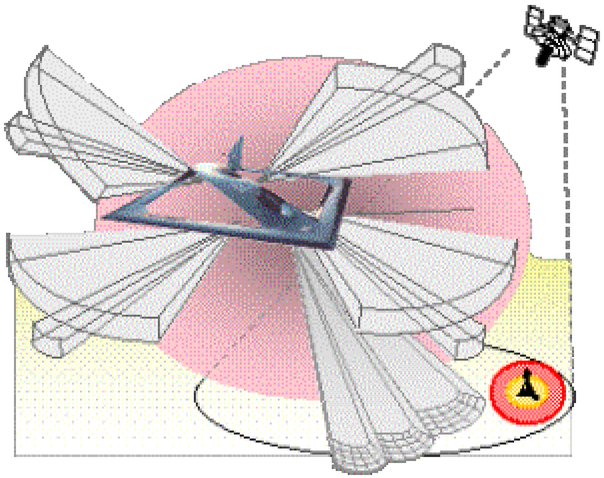
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**23**	

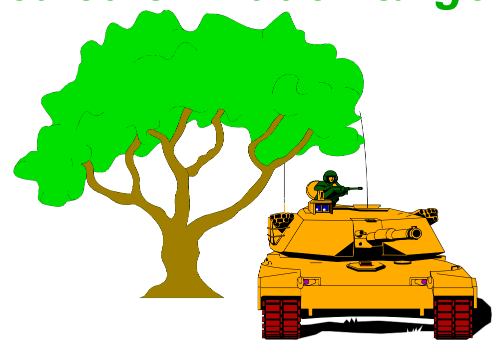
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Sensor Craft Initiative

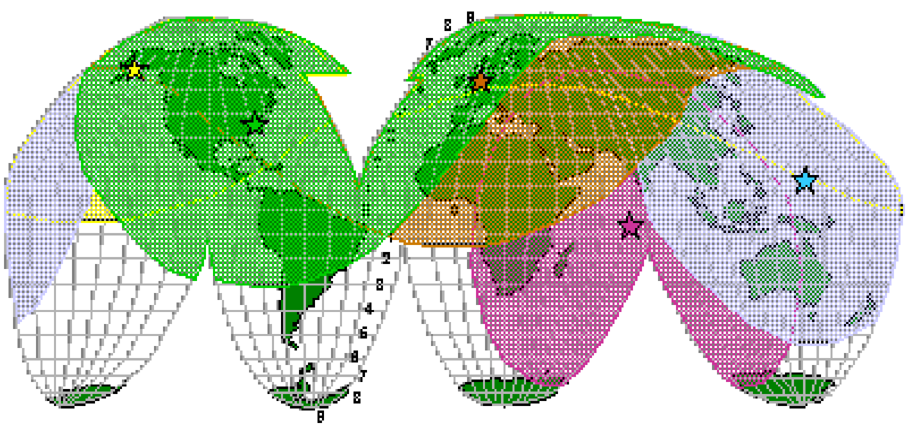
Transforming Vision to Reality



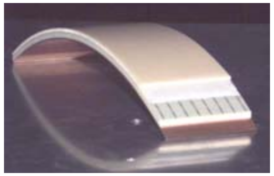
Detection, tracking, and targeting of concealed or hidden targets



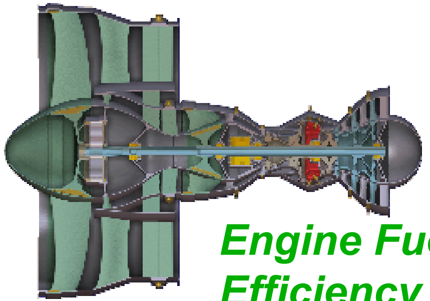
Eyes and Ears of Warfighter
Worldwide 24/7 Coverage



Enabling AFRL Technologies



Conformal Load Bearing Antenna



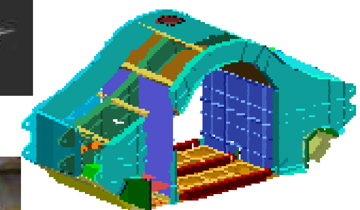
Engine Fuel Efficiency

Aerodynamic Optimization

The Airbreather Component of the "Fully Integrated" ISR Enterprise

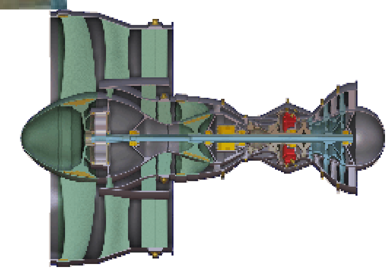
AFRL Technical Challenges
SensorCraft Technologies

Air Vehicle
- Structurally integrated radar apertures
- High efficiency aerodynamics
- Lightweight aircraft structures

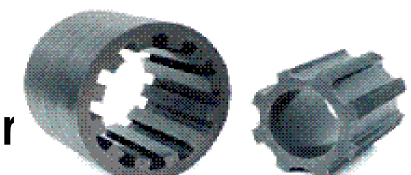


Sensors
- Beam forming across complex surfaces
- Affordability and advanced sensors
- Fully flexible waveforms

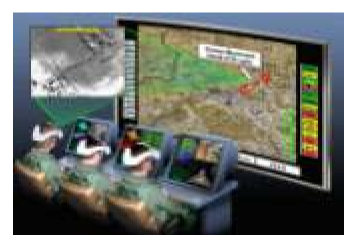
Information
- Off-Board BM/C2, TCPED, FUSION-ATR



Propulsion
- Magnetic bearings / Integral Starter Generator
- High altitude, long endurance fuel burn reduct
- Full life hot section and maintenance free engine core

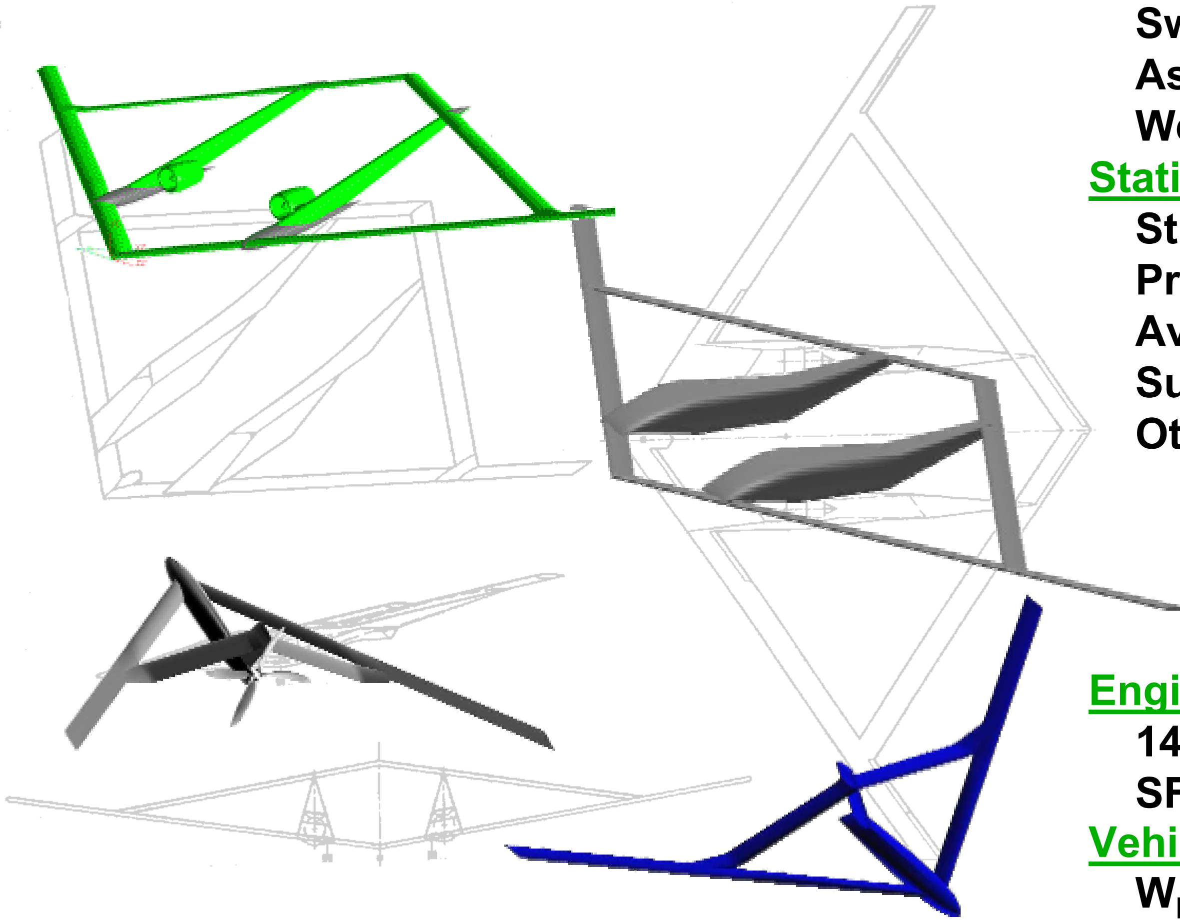


Materials
- Wide Bandgap RF Semiconductors and Polymers
- Higher Temperature Turbine Engine Materials
- Affordable, Lightweight Structural Materials



VA SensorCraft Tech Assessment
Trade Space Analysis

Statistical Sizing
"40 Hr Statistical Air Vehicle"



Sized Geometry

- Wing Area (Gross): 2300 Sq Ft
- Span: 214 Ft
- Length: 118.6 Ft
- Sweep: 35 Deg
- Aspect Ratio (Gross): 17.4
- Wetted AR: 5.5

Statistical Weights (Lbs)

Structure:	17500
Propulsion:	3700
Avionics:	1000
Subsystems:	3000
Other :	1400
Empty Weight:	26600
Payload Weight:	4000
Fuel Weight:	39400
Gross Weight:	70000

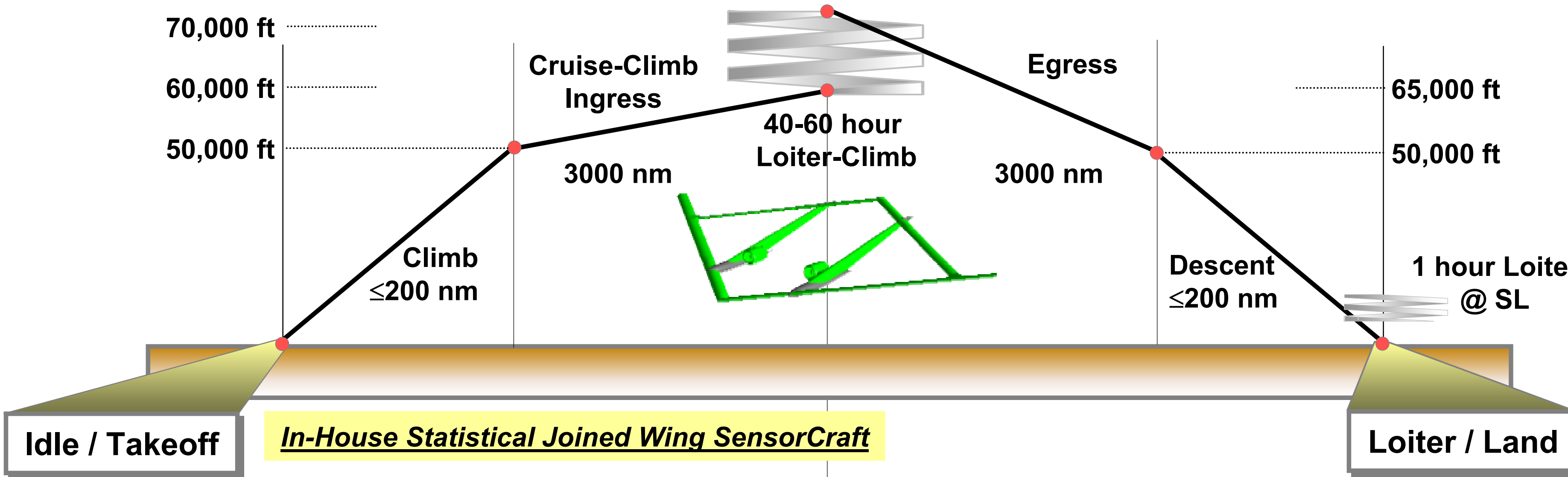
Engines (2)

- 14000 lb St Thrust (CF - 34B Class)
- SFC: 0.38

Vehicle Characteristics

- W_E/W_{TO}: 0.38
- L/D: 32

Multipoint Efficiency Challenge



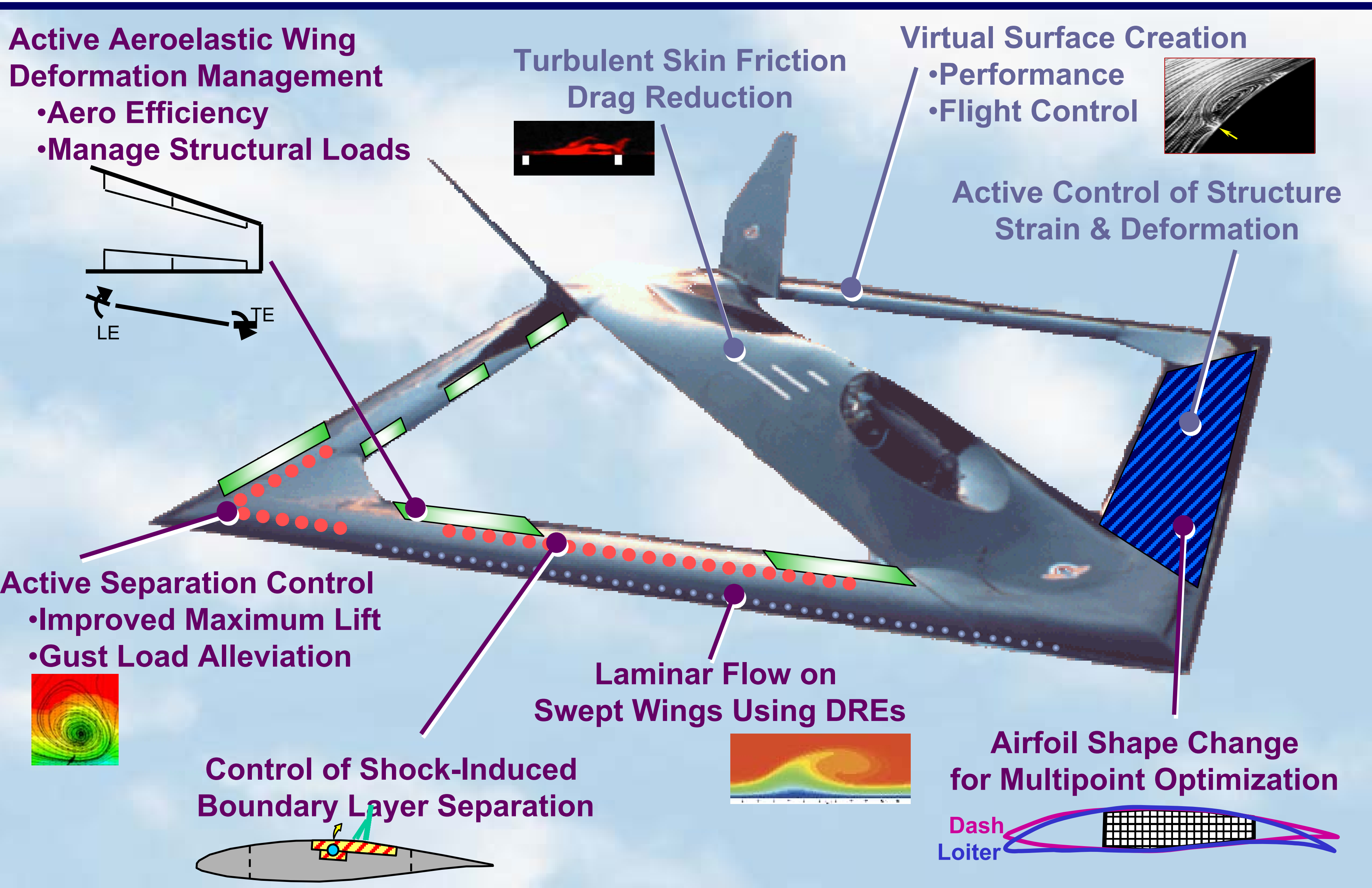
WEIGHT	75,000	71,677	62,150	35,200	34,000	30,000
Mach	0.25	0.6	0.6	0.6	0.6	0.2
Q (psf)	93	61	38	24	61	59
V (fps)	280	581	581	583	581	224
C_L	0.35	0.51	0.711	0.637	0.24	0.22
Re(Millions/ft)	1.8	0.71 – 0.44	0.44	0.27	0.27 – 0.71	1.43
Re_c(millions)	11.7	4.615-2.86	2.86	1.755	1.755-4.615	9.3

Numbers Based On Notional SensorCraft Mission Profile ; $S=2300\ ft^2$; $W/S|_{TO}=30$ $c=6.5ft$

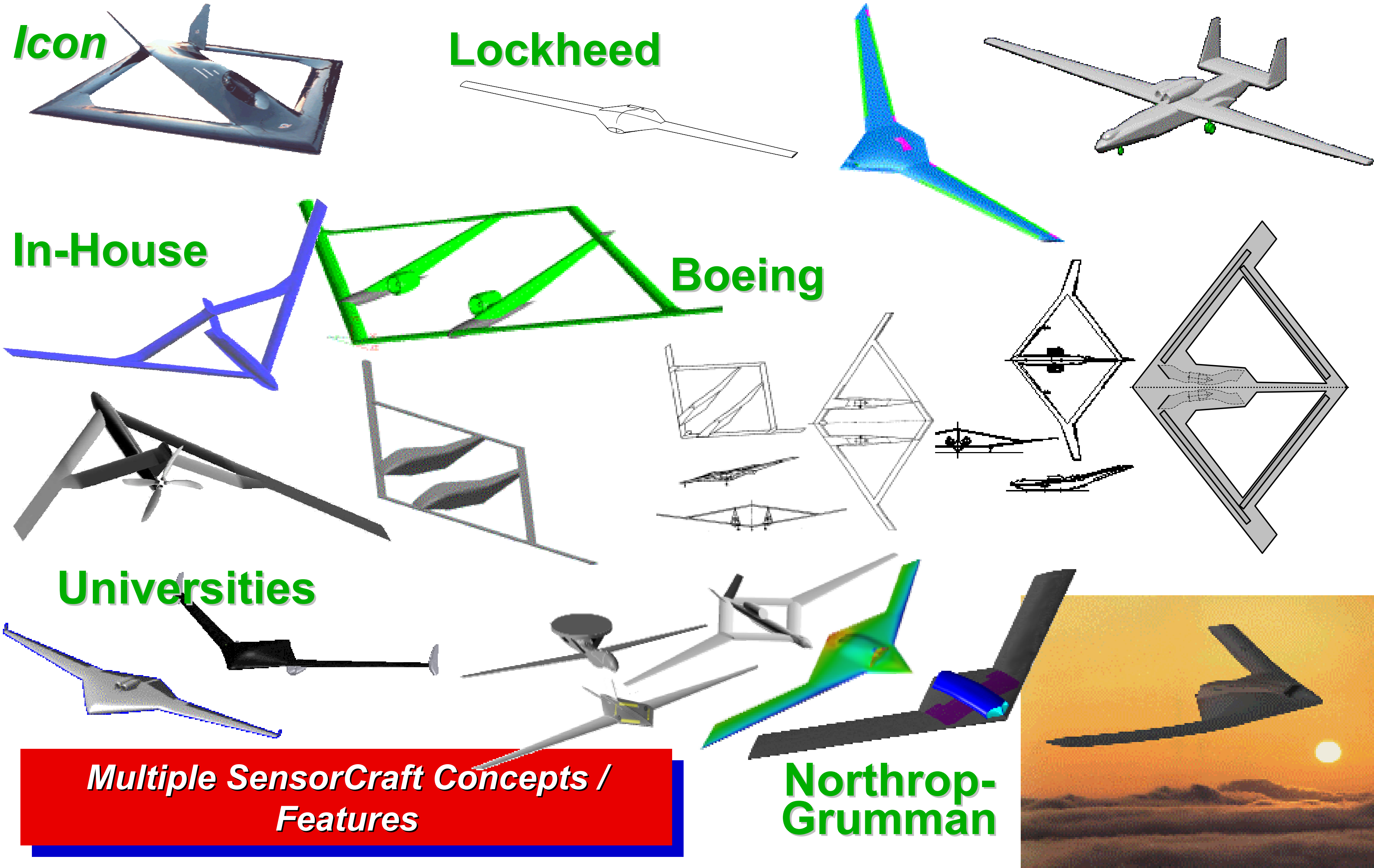
Single-point Design Is Not Sufficient for Sensorcraft Mission

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S} = \frac{L}{\frac{1}{2}\gamma p M^2 S} = \frac{W/S}{q}$$

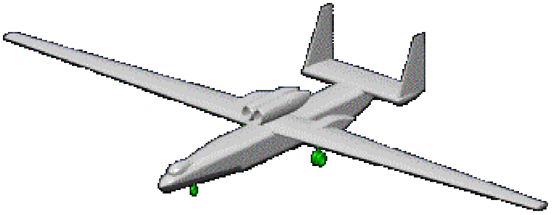
Technology Applications for Sensorcraft



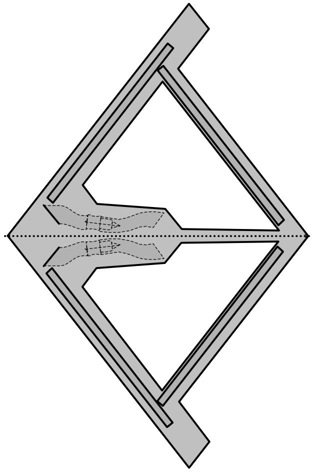
SensorCraft Concepts



Primary Aerodynamic Challenges



- Operates over a large range in C_L & Re
- Limited coverage (side lobes)
- Low survivability (very detectable)
- Large aeroelastic deflections



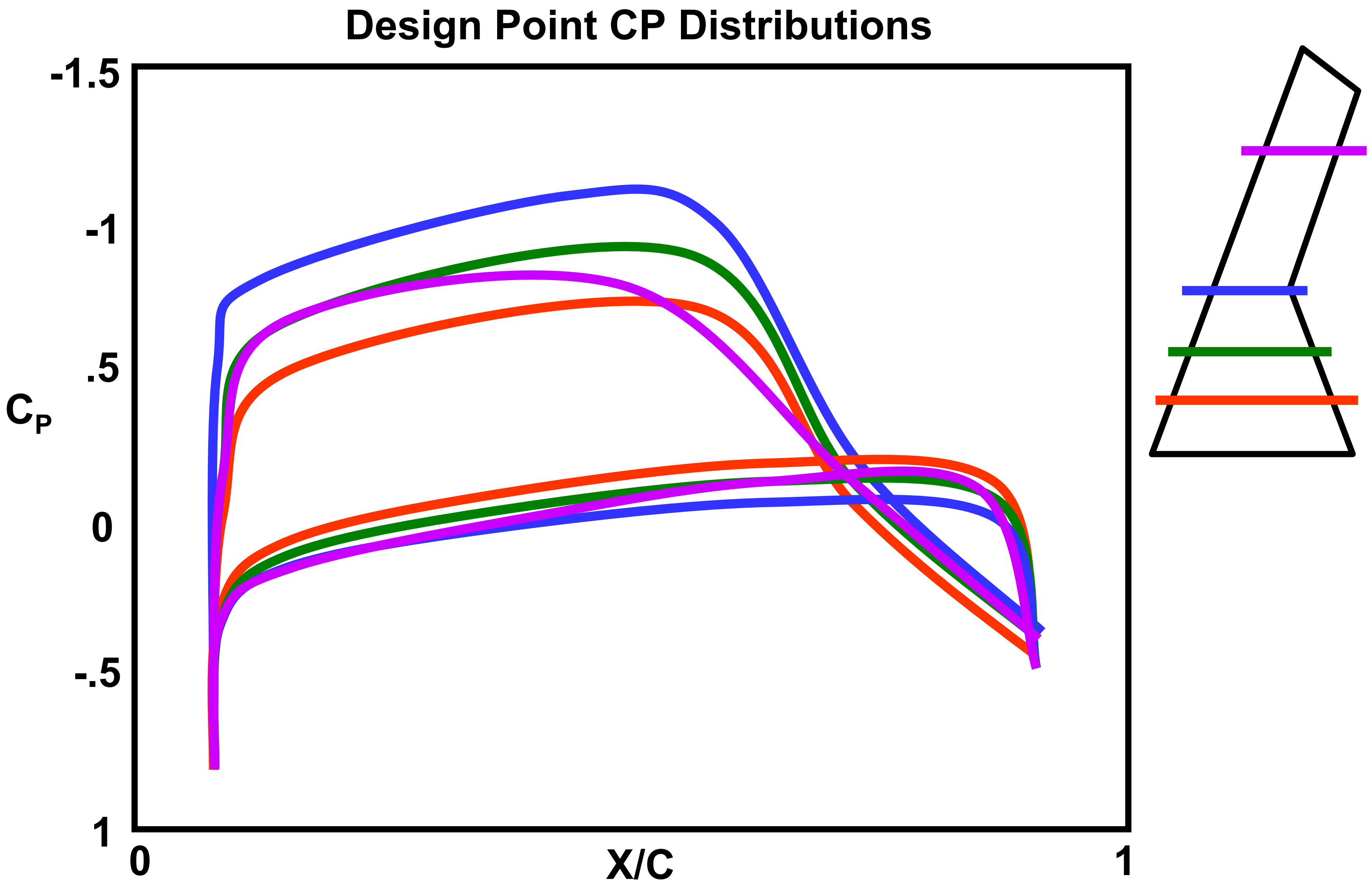
- Operates over a large range in C_L & Re
- Crossflow instabilities destroy laminar boundary
- Joined-wing juncture flow
- Joined-wing structural modes not completely understoo
- Propulsion integration (?)

- Operates over a large range in C_L & Re
- Crossflow instabilities destroy laminar boundary
- Joined wing juncture flow
- Stability & control considerations
- Highly loaded airfoil at break
- Large aeroelastic deflections

Sensor / Aero Interactions

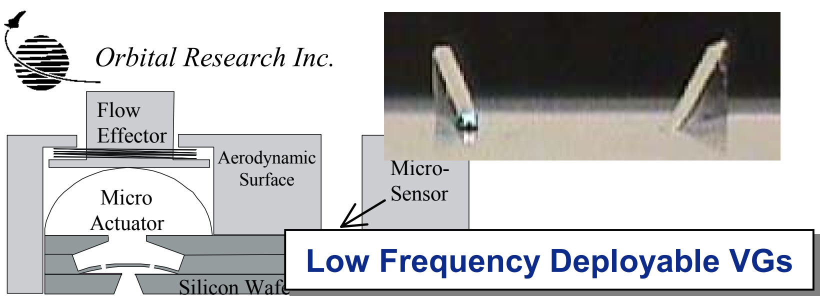
- **Placing sensors & antennae on a flexible wing requires attention to:**
  - deflections which may impact sensor performance
  - impact of sensor on wing performance
    - Aeroelastic
    - Aerodynamic
    - Control surface placement
- **Recurring challenge: Allocating vehicle real estate between antennas and control surfaces**
  - Stem from the desire for the antennas to have 360-degree views
  - types of antennas can exacerbate problem

Wing Loading Distribution



Novel Active Flow Control Devices
Advances Through Processes, Materials, MEMS

Displacement Amplification Compliant Structure Producing Amplified Motion of 5mm @240Hz



(Co-Located Actuator and Sensor)

Micro-VG Deployed Pneumatically by Opening MEMS Air Valve

- **Objective**
  - Create vortex pulses for active separation control with very low energy requirements on the system
- **Approach**
  - Dynamic micro-VGs to convert the freestream energy into BL
  - Test in Wind Tunnel
- **Examples**
  - Compliant structure with 20:1 displacement amplification
  - Arrays Co-Located Actuator and Sensor pairs enabled by MEMS technology

Benefits of HiLDA Active Wing Tech

Active Wing Technologies	C_{d_o} ↓	C_{d_i} ↓	$C_{L_{op}}$ ↑	$C_{L_{max}}$ ↑	Wt ↓
AFC – Laminar Flow Control Using DRE (Static)	✓				
AFC – Pulsed Vortex Generator Jets (Dynamic)		✓	✓	✓	
AAW		✓			✓
AS – Hingeless, Spanwise Variable LE and TE CS		✓	✓	✓	
AFC + AAW + AS	✓	✓	✓	✓	✓

1h0021-014

- Individual and Synergistic Benefits of Active Wing Technologies are Being Evaluated

Technology Cross Influences

	AFC-DRE	AFC-PVGJ	AAW	AS	AS-$C_{Di\ min}$
AFC-DRE		⊗	⊗	⊗	⊗
AFC-PVGJ			◉	●	●
AAW				◉	⊗
AS					
AS-$C_{Di\ min}$					

Legend:
- ⊗ Interaction Needs to Be Studied
- ● No Interaction Foreseen
- ◉ Cumulative Effectiveness Reinforce Each Other

1H0021-028

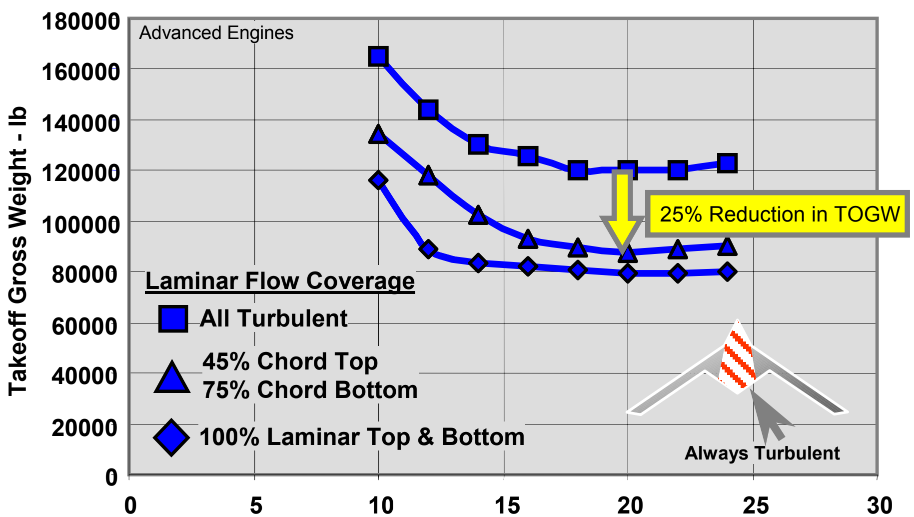
NORTHROP GRUMMAN
Integrated Systems

- AS Control Surfaces for AAW Applications
- Study Influence on Laminar Flow of PVGJ, AAW, and AS

Laminar Flow on Swept Wings

Distributed Roughness Elements

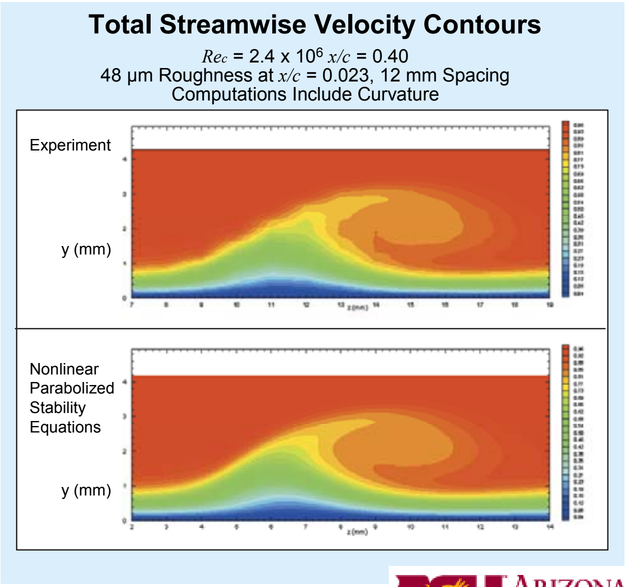
PAYOFF:



PROBLEM: Crossflow Induced Transition

Favorable pressure gradient stabilizes traveling (TS) waves in boundary layer, but does not affect stationary (crossflow) waves. In the past, suction has been required for crossflow stabilization.

SOLUTION: Distributed Roughness Elements (DREs) of the proper spacing (wavelength) and size can create "favorable" disturbances that overwhelm the amplified-wavelength disturbances that otherwise lead to transition.



ARIZONA STATE UNIVERSITY

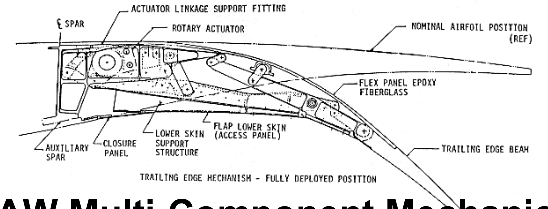
Benefit to Sensorcraft: Laminar Flow Results in Large TOGW Reductions

Many DRE Questions Remain

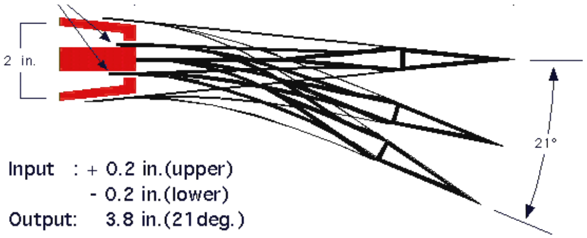
- How to design distribution.
- Is it robust?
  - M, C_L, Re
  - Bending, twist, environments
- Must it be active or adaptive?
  - Spacing, placement, bump height, dimple depth…
  - If so, how do we change the distribution?
- How do we demonstrate it?
  - Tunnel, flight test, flight experiment, combination?
  - Under what conditions?
- Will it work at high C_L?

Adaptive Structures Applications for Sensorcraft

Trailing Edge

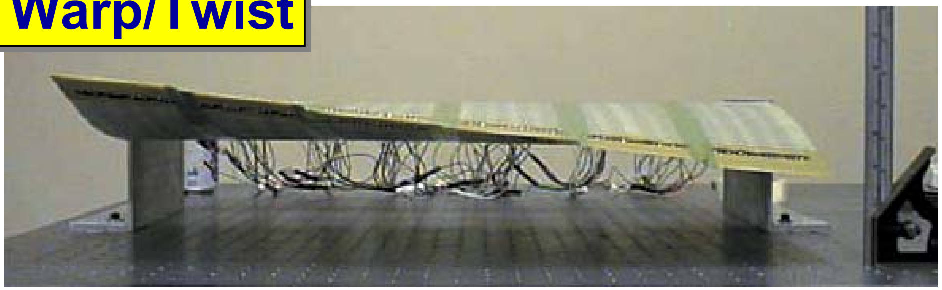


MAW Multi-Component Mechanical Structure Trailing Edge Flap Design

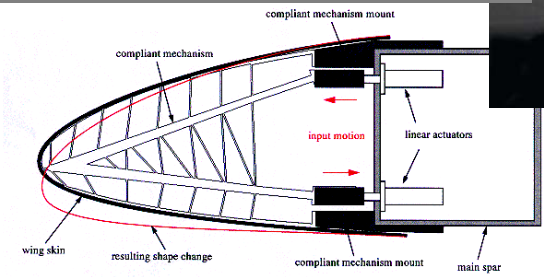


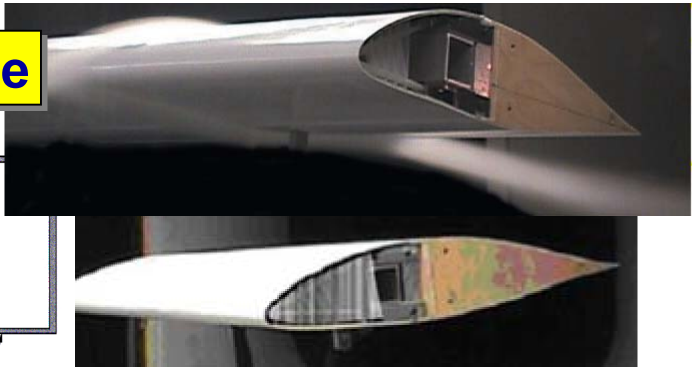
Equivalent Compliant Structure Trailing Edge Flap Design

Wing Warp/Twist

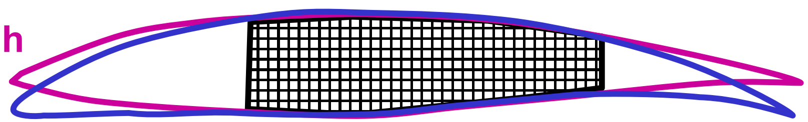


Leading Edge Shape





Wing Camber



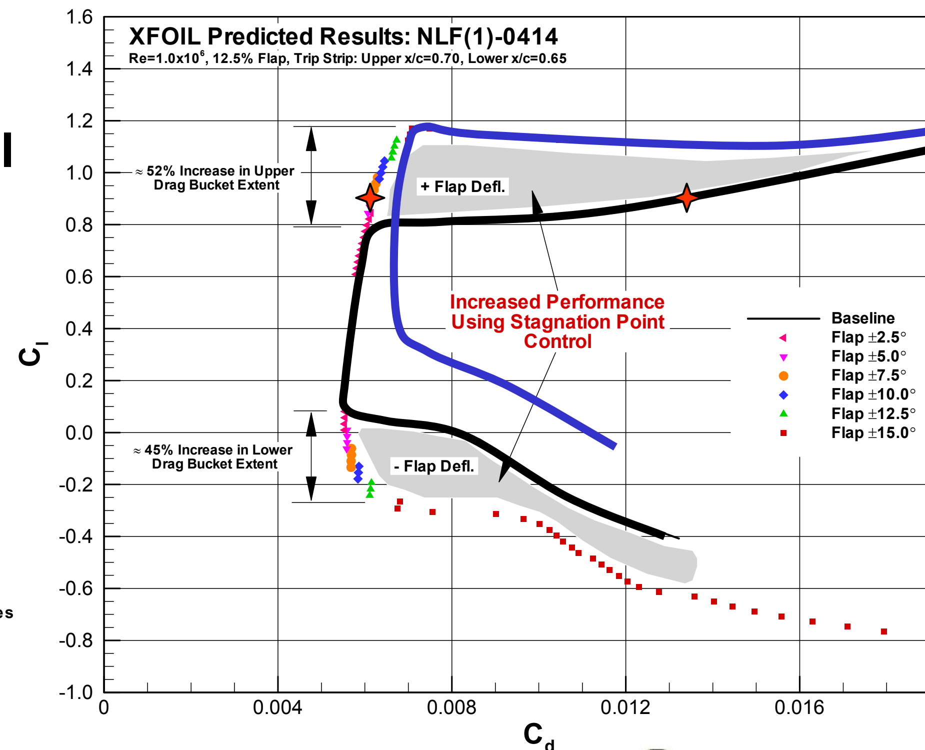
For Sensorcraft, Adaptive Structures Are being Applied to:

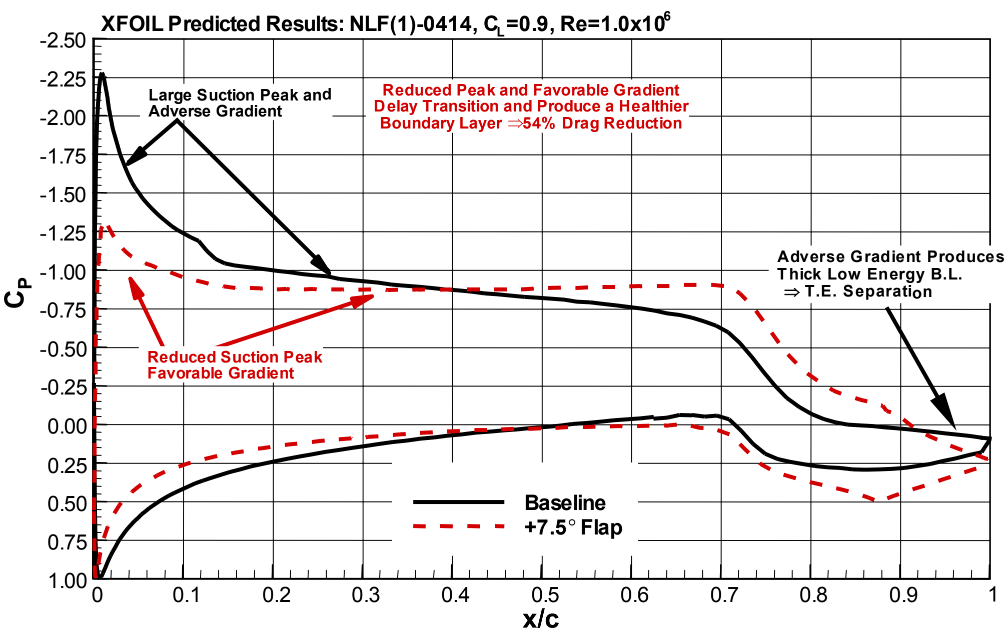
- ***Control Wing Shape for Optimal Aerodynamic Performance Throughout the Mission***
- ***Manage & Alleviate Structural Loads***

Adaptive Compliant Trailing Edge

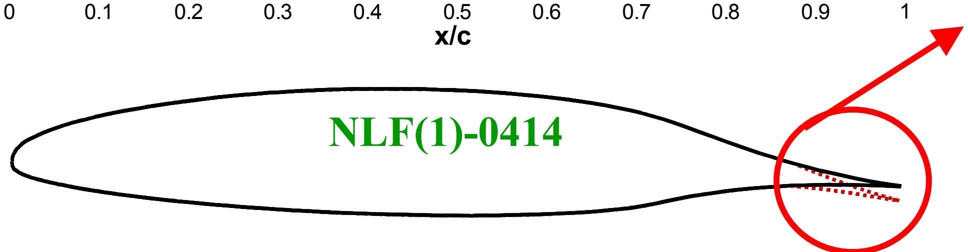
Tailoring Airfoil Performance

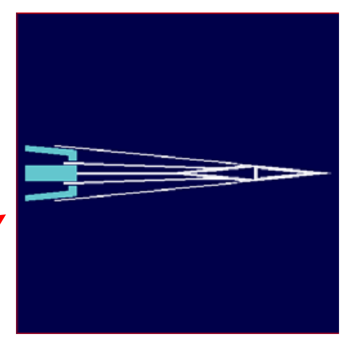
- **Variable geometry compliant trailing edge**
- **Adaptive TE expands low drag bucket via stagnation point/pressure gradient control**
- **Allows entire loiter to be performed at exceptionally high airfoil L/D (≈125-165)**





EIDETICS CORPORATION

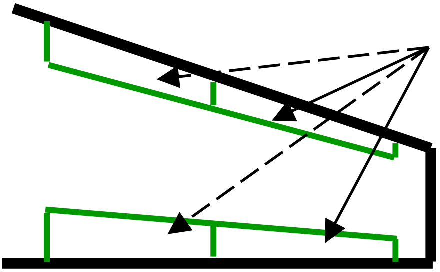


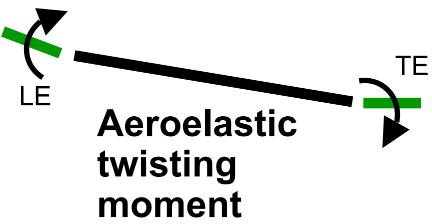


FlexSys Inc.

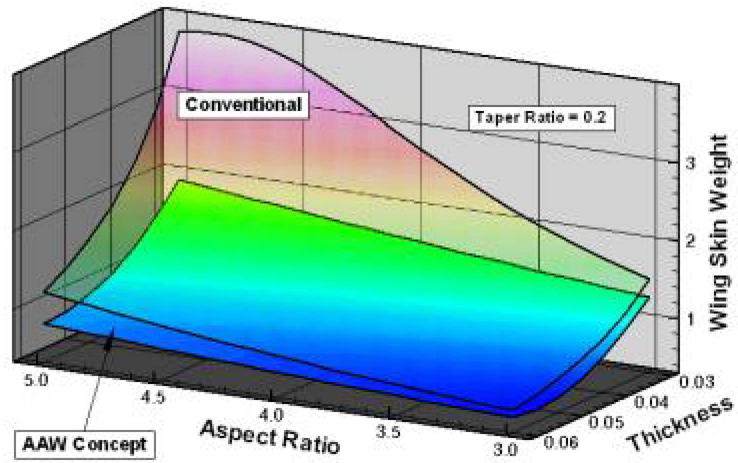
Adaptive Trailing Edge Alone Maintains "Low-Drag Bucket" Over Wide Range of C_L

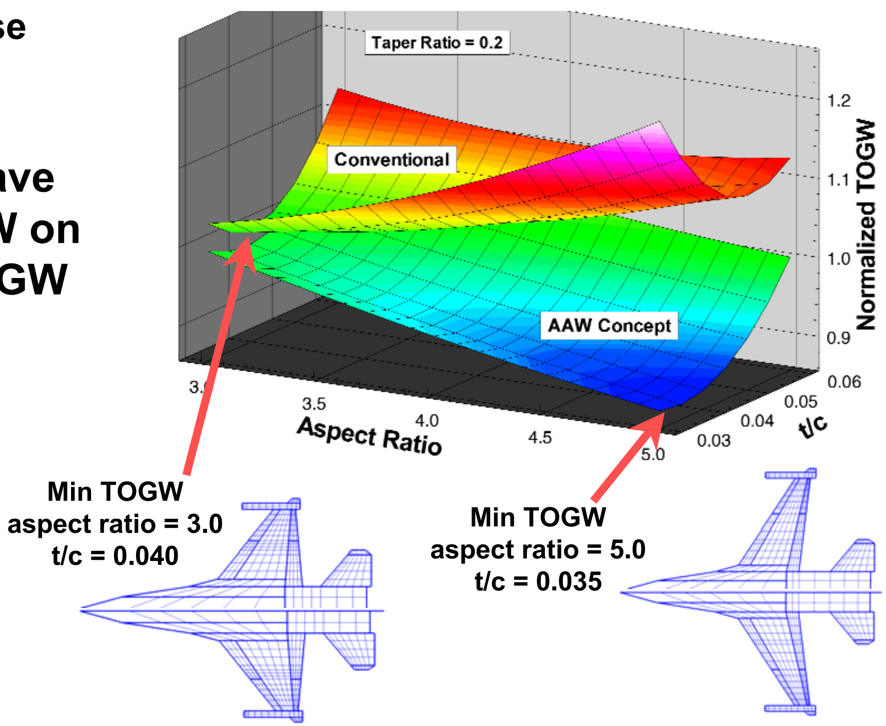
AAW and Application to Sensorcraft





- Basic AAW uses conventional control surfaces to aeroelastically shape the wing throughout the mission
- In fighter applications, AAW exploits wing aeroelasticity for:
  - structural load reduction
  - control authority increase
  - induced drag reduction
- Fighter design studies have shown the impact of AAW on structural weight and TOGW



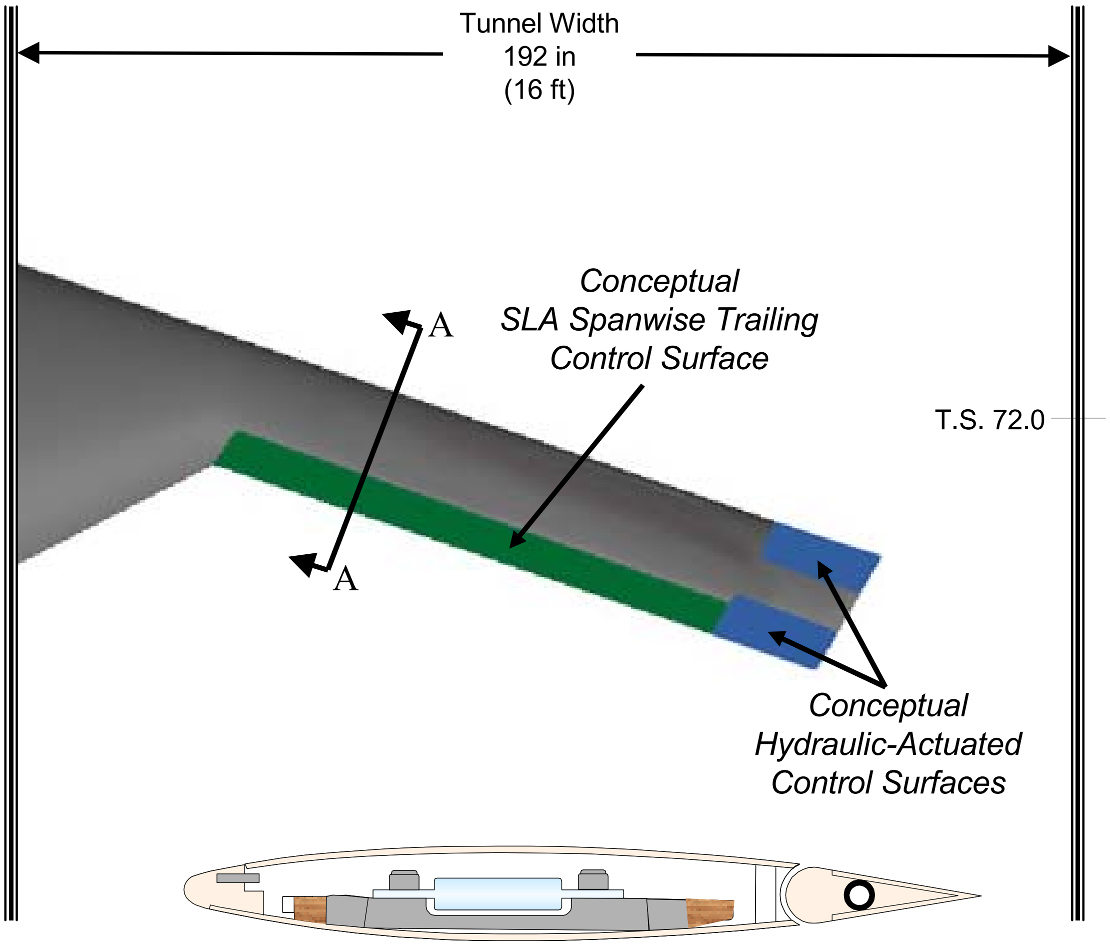


For Sensorcraft AAW Could:

- ***Reduce Structural Design Loads***
- ***Improve L/D***
- ***Improve Antenna Performance***

NGC Task 2
Wind Tunnel Model Installation

NASA/Langley TDT



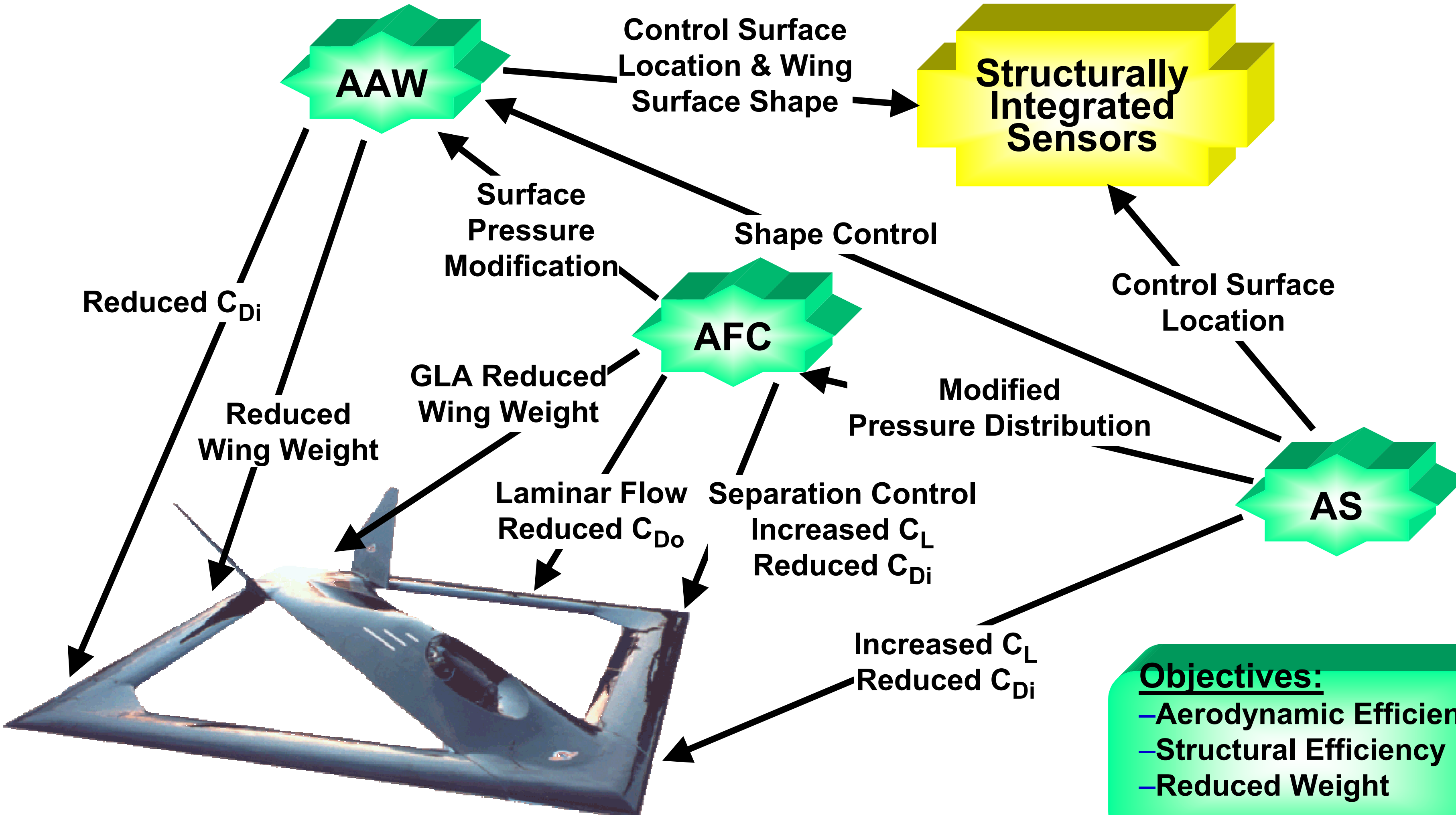
Section A-A

- Model to be Mounted Off Side Wall
  - Model Pitch and Plunge Restrained
- Shape Control Achieved with Combination SLA Trailing Edge and Hydraulic Actuated Control Surface
- Gust Load Alleviation (GLA) Test Using Hydraulic Actuated Control Surface
- Different Test Mediums for Each Test Goal
  - Shape Control – Air
  - GLA – R134a

NORTHROP GRUMMAN Integrated Systems

HiLDA

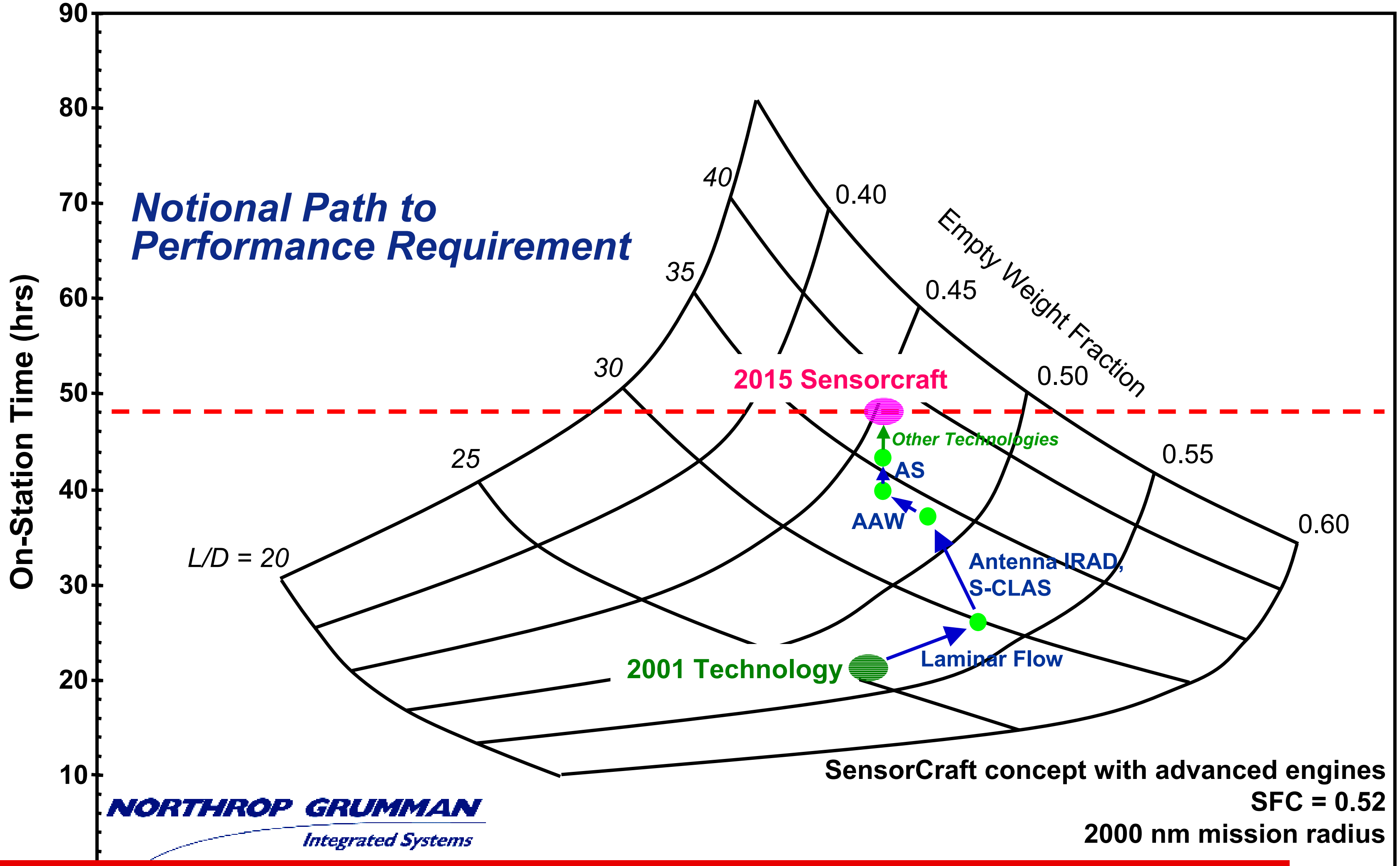
Technology Interactions



Objectives:
- Aerodynamic Efficiency
- Structural Efficiency
- Reduced Weight

- ***Interaction of Technologies Key to Integration***
- ***Must be Compatible with Sensors (Materials, Location, etc.)***

Flow Control is in Competition with Other Technologies



- ***Active Wing Technologies Have the Potential to Significantly Impact SensorCraft Design & Performance***
- ***The HiLDA Program Will Provide Needed Quantitative Information***

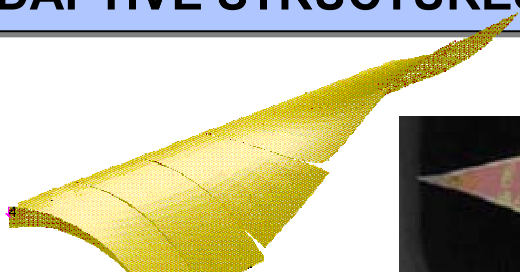
High L/D Active (HiLDA) Wing

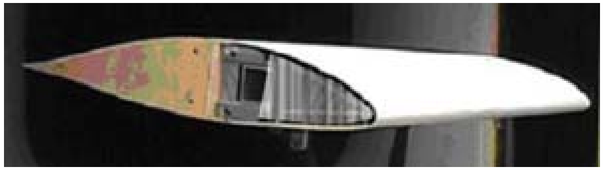
OBJECTIVES:
- Apply AFC, AAW, and Adaptive Structures, to a Sensorcraft wing design for load reduction and improved L/D
- Demonstrate critical technologies in wind tunnel
- Prepare for demonstration of high aerodynamic efficiency in upcoming 6.3 program

PAYOFFS:
- Reduced structural loads and improved L/D for Sensorcraft vehicle weight reduction

APPROACH:
- Apply AAW to Sensorcraft wing configuration & evaluate structural weight savings and L/D improvement
- Determine optimum airfoil shape throughout mission profile
- Evaluate active flow control methods to alleviate off-design requirements
- Apply active flow control and adaptive structure design to maximize aerodynamic efficiency
- Demonstrate integrated design in wind tunnel

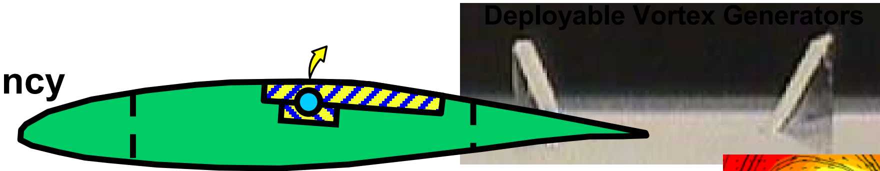
ADAPTIVE STRUCTURES



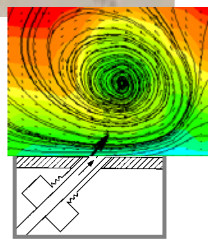


Adaptive Wing Shape for Drag Minimization and Gust Load Alleviation

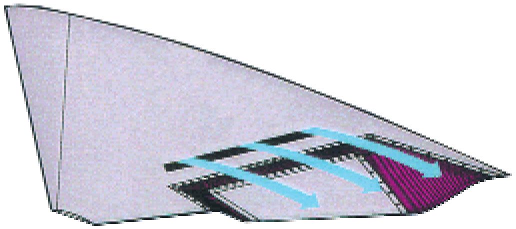
ACTIVE FLOW CONTROL



Shock-induced Separation Control

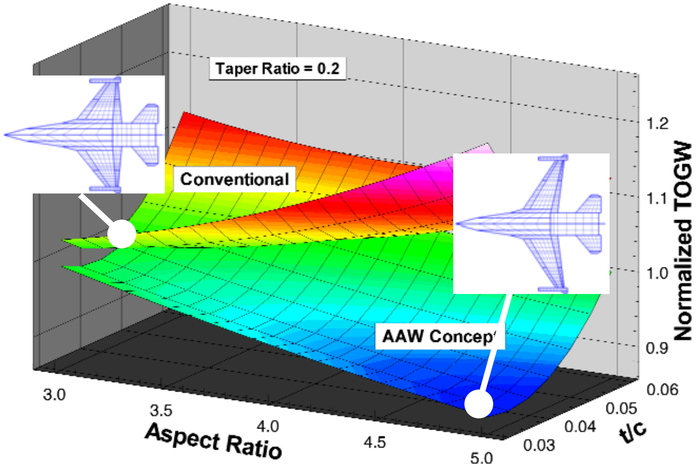


Pulsed Jets

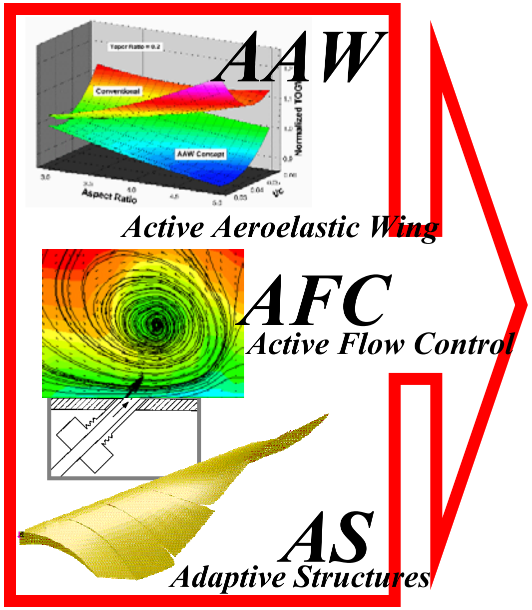


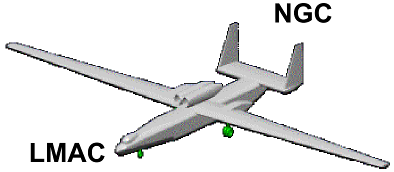
Control Surface Augmentation or Replacement

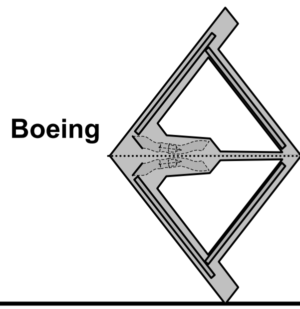
ACTIVE AEROELASTIC WING



High L/D Active (HiLDA) Wing







Objective

- Prepare for demonstration of ultra-efficient wing in upcoming 6.3 program

Problem

- Need significant increases in structural and aerodynamic efficiency to meet range/loiter requirements Sensorcraft concept.
- Reduced structural loads and improved L/D for Sensorcraft vehicle weight and cost reduction

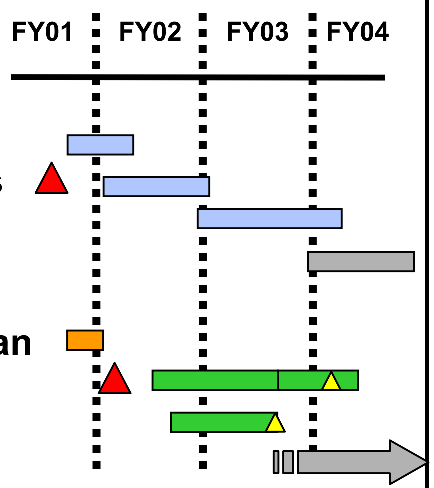
Customers

- NASA, UAV, Sensorcraft, ASC/RA, ACC-ISR

Schedule / Milestones

<u>TASK 1</u> (LMAC, NGC)
- Technology Assessments
- Integrated Benefit Analysis
- Active Wing Design
- AAW (Boeing)

<u>TASK 2</u>
- Develop Tunnel Testing Plan
- Design, Fab, & Test (NGC)
- DRE Quick Look (LMAC)
- DRE Robust



Technical Challenges

- Determine individual and combined technology impacts on Sensorcraft
- AAW/AFC/AS specific issues
- Integrated design of active wing to max. efficiency

Players

Partners
- NASA

Performers
- Task 1 - Lockheed, Northrop
- Task 2 - Lockheed, Northrop, Boeing